Dynamical constraints linking Earth co-orbital asteroid Kamoʻoalewa to the lunar Giordano Bruno impact. Yifei Jiao, Bin Cheng, Yukun Huang, Erik Asphaug, Brett Gladman, Renu Malhotra, Patrick Michel, Yang Yu and Hexi Baoyin. Tsinghua University, Beijing, 100084, China, Department of Physics and Astronomy, University of British Columbia, Vancouver, BC, V6T 1Z1, Canada, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, 85721, USA, 4Université Côte d’Azur, Observatoire de la Côte d’Azur, CNRS, Laboratoire Lagrange, Nice, France, 5Beihang University, Beijing, 100191, China.

Introduction: The asteroid 469219 Kamoʻoalewa (2016 HO3) has attracted great interest since its discovery. With an Earth-like semi-major axis of ~1 au, low eccentricity, and low inclination, Kamoʻoalewa exhibits a 1:1 mean-motion resonance (persisting for ~Myr time scale) with Earth, switching between a quasi-satellite state and a horseshoe configuration during the long-term evolution [1]. As a close and long-standing companion to our planet, Kamoʻoalewa has garnered significant attention as a prospective target for in-situ exploration, and China’s Tianwen2 mission is scheduled to visit this asteroid in 2027 [2].

The asteroid Kamoʻoalewa rotates much faster than most asteroids, with a period of 28.3 ±1.8/-1.3 minutes [3], so must have at least some cohesion. Its absolute magnitude of 24.3; for albedos from 0.1 to 0.25 this corresponds to an effective diameter 60 m to 36 m. The reflectance spectrum provides further clues about its physical properties and compositions: the 1.0-micron absorption indicates a mineral composition mainly of olivine and/or pyroxene; and the weak band depth and unusual steep red slope is consistent with lunar-style space weathering [3]. This may suggest a possible lunar origin rather than a migration from the main asteroid belt, thereby motivating further dynamical investigations. Some recent work has reported the existence of orbital pathways for lunar launched particles to enter the Kamoʻoalewa-like orbits [4].

In this context, this work presents further constraints for Kamoʻoalewa’s lunar ejecta origin in terms of both cratering and dynamical aspects. We show that a sufficiently energetic collision within the past few million years on the Moon could have ejected high-velocity fragments into heliocentric orbits, with some of them present in 1:1 Earth-resonance orbits at the present day. Such a scenario leads us to suggest the young lunar crater Giordano Bruno as a possible source, and to explore the ejection mechanisms, ejecta dynamics, and scientific implications for such an origin.

Dynamical Constraints: To constrain the crater on the Moon that could have produced Kamoʻoalewa, we simulate crater formation using an impact hydrocode [5] using the smooth particle hydrodynamics and the Weibull-based fracture damage model of [6]. A range of impact velocities and angles have been investigated. We find that to obtain impact fragments that are faster than lunar escape velocity of 2.38 km/s and larger than Kamoʻoalewa’s size of at least 36 m, the impactor’s minimum size is ~1 km, resulting in a final crater of 10 to 20 km according to the lunar scaling. Another constraint is that the median NEA dynamical lifetime for ejecta is about 10 to 100 Myr [7], leaving only few candidates, e.g., the Giordano Bruno crater (22 km diameter, 1 to 10 Ma age [8]). Since GB is the youngest of these by a significant fraction, we focus on it as the potential source. A possible support could be the similarities in the spectra of Kamoʻoalewa and the Luna 24 sample, which may contain ejecta material from the GB crater [9].

We have predicted hundreds of escaping fragments of Kamoʻoalewa’s size in our impact simulations. Then, we perform N-body simulations investigating the long-term dynamical evolution of the escaping GB ejecta, initialized with various launch velocities, azimuths, and lunar phases. Most of the launched particles end up in collisions with the Earth, causing a roughly ten-fold spike in (now unobservable) lunar meteorites delivered to Earth for the first ~1 Myr after GB formation. Some particles will survive in heliocentric orbits over 10 Myr, including a small fraction that evolve in Earth co-orbital configurations.

The cratering and dynamical simulations allow us to constrain the source crater’s size and age to obtain at least one Earth co-orbital object at the present day. As shown in Figure 1, the large and young craters (upper left corner) are more probable sources, as they produce more escaping fragments that still stay in space and even the Earth co-orbital region, and indeed GB is the only possible source crater satisfying the criterion.

**Figure 1.** Source crater criterion to obtain at least one Earth co-orbit at the present day. Using our simulated results as a baseline, we can further constrain all possible source craters based on their estimated ages and sizes. The dashed line shows the nominal largest crater size over time according to Neukum’s model, indicating that GB is unusually larger than the average.